Building Performance Simulation
for
Sustainable Energy Use in Buildings

Jan Hensen

- context
- current state
- challenges & approaches
- conclusions

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts

www.bwk.tue.nl/bps/hensen

Current energy use

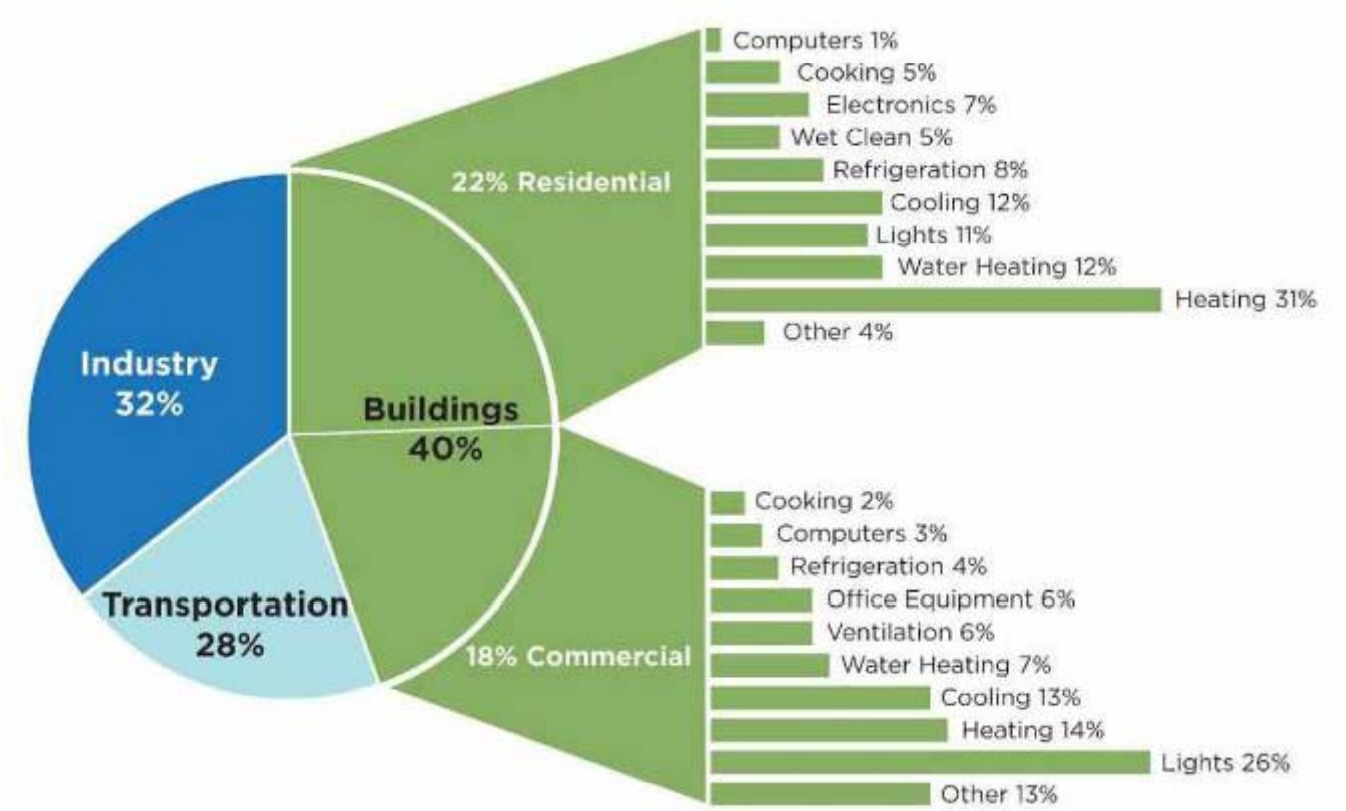


Figure 1. Energy Consumption in the United States
Source: 2007 DOE Buildings Energy Data Book, Tables 1.1.3, 1.2.3, 1.3.3

Green design guidance

performance

Voluntary “best green” performance of some buildings

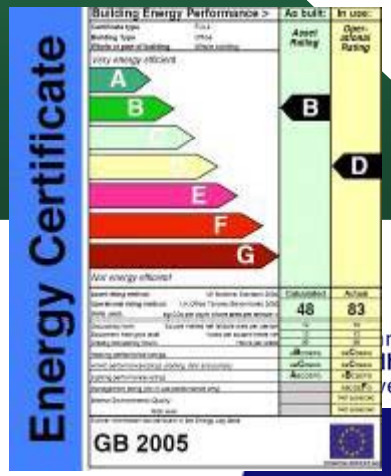
More complex tools are acceptable

LEED, BREEAM, CASBEE, ...

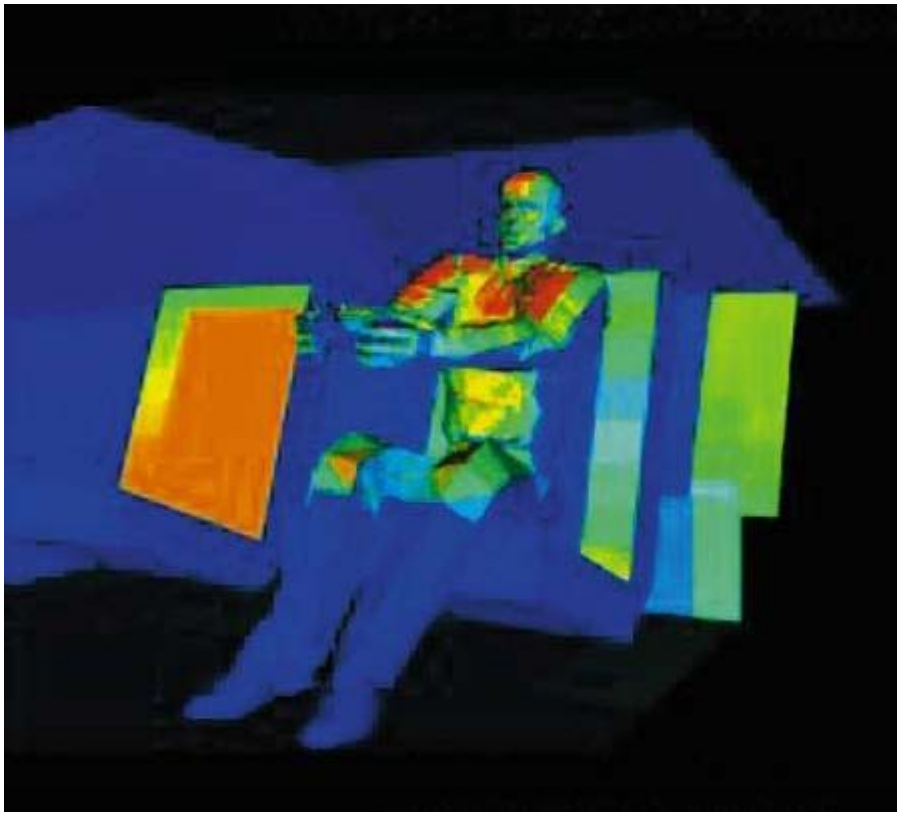
Mandatory minimum energy performance of every building

Tools must be as simple as possible

EPBD



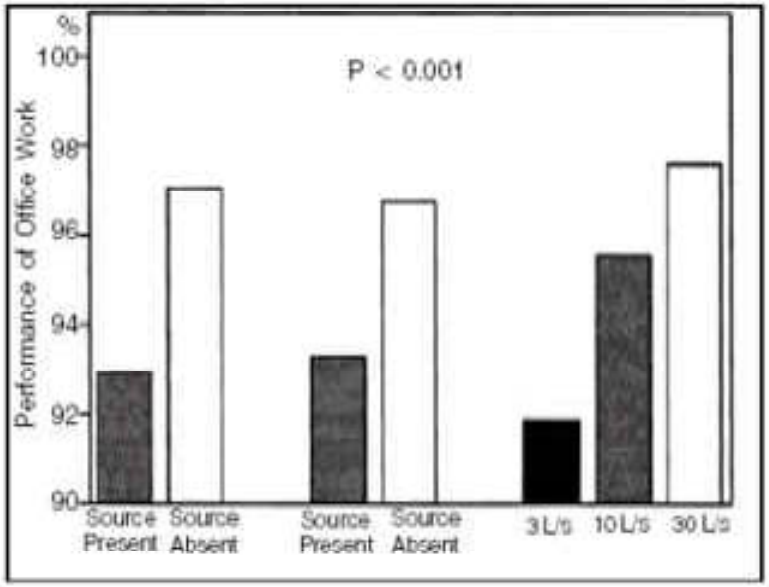
Increasing comfort demands



source: www.automotiveworld.com

source: www.learn.londonmet.ac.uk

Indoor quality vs. productivity



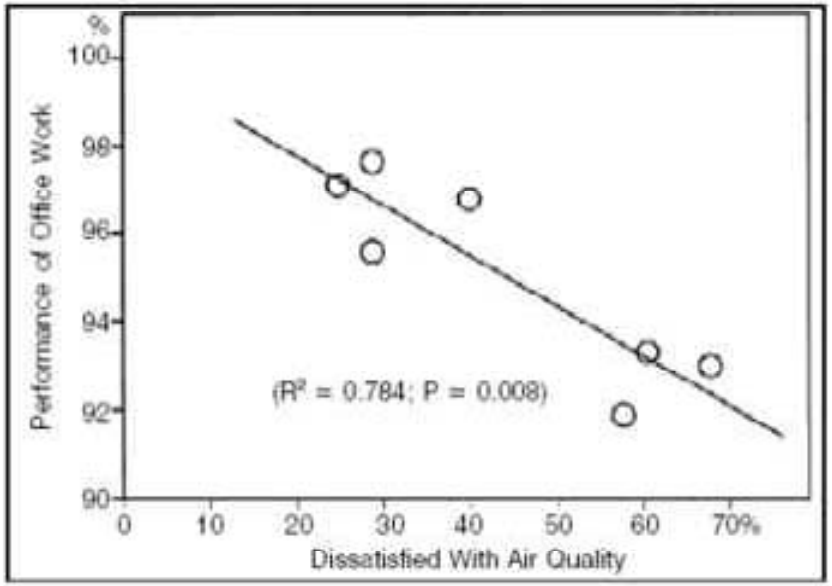
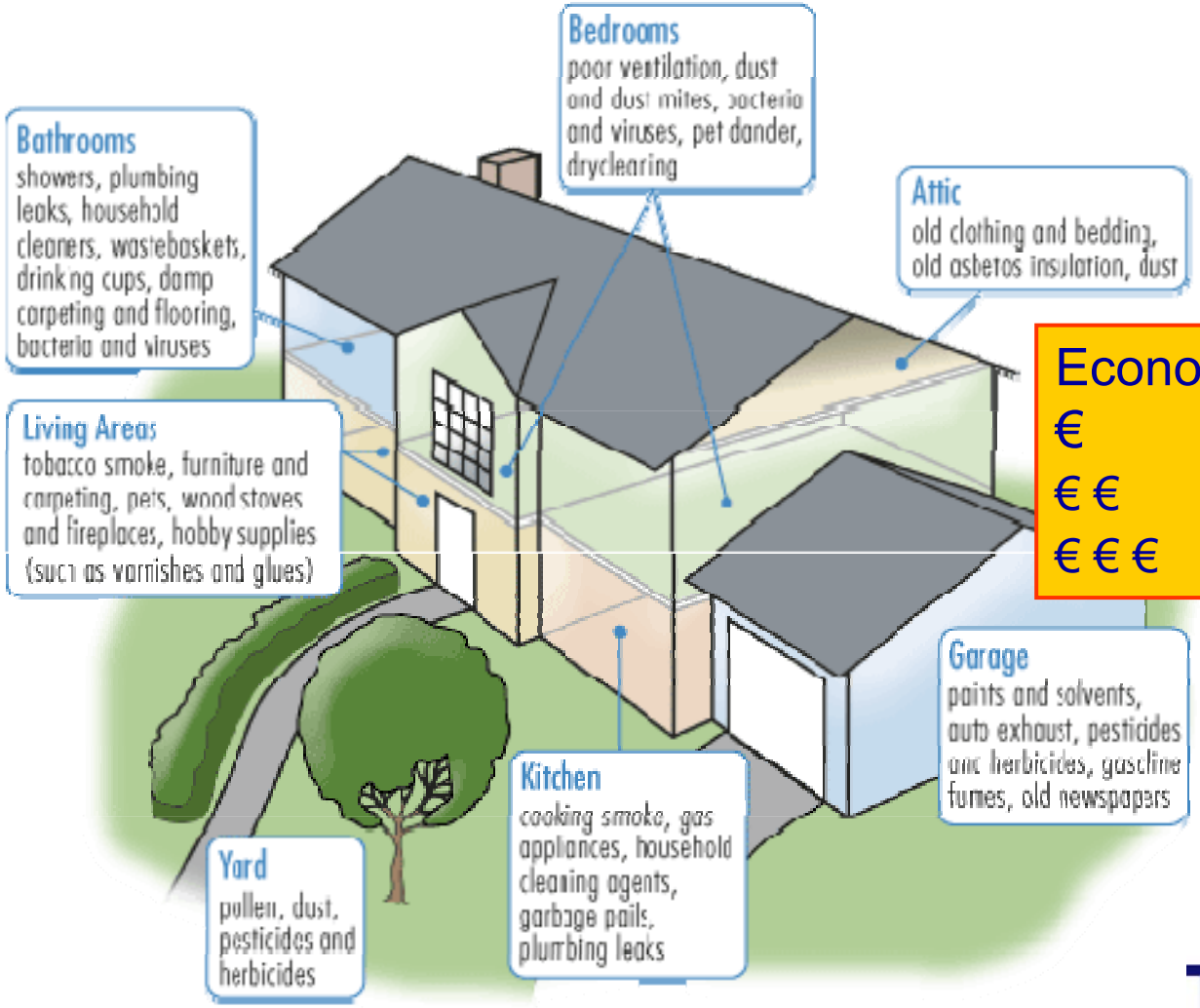


Figure 1 (left): Performance of office work as a function of the presence or absence of the pollution source, or the outdoor air supply rate. Figure 2 (right): Performance of office work as a function of the perceived air quality.

source: Wargocki, P 2002 "Making the Case For IAQ", ASHRAE IAQ Applications

Indoor quality vs. health

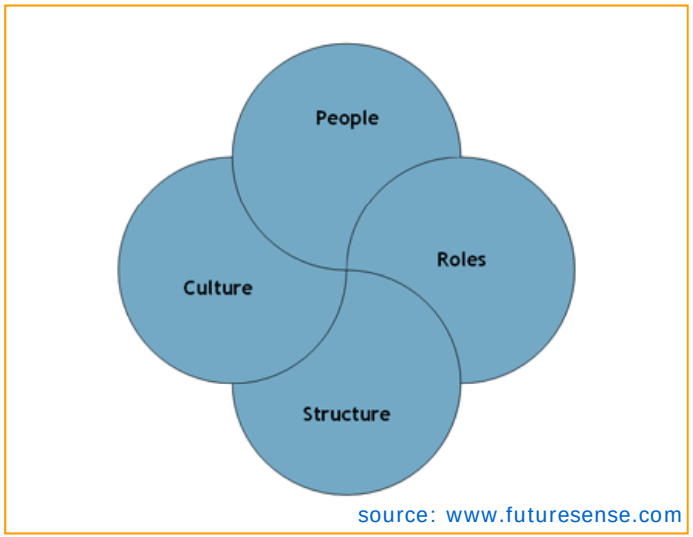


Economic impact:

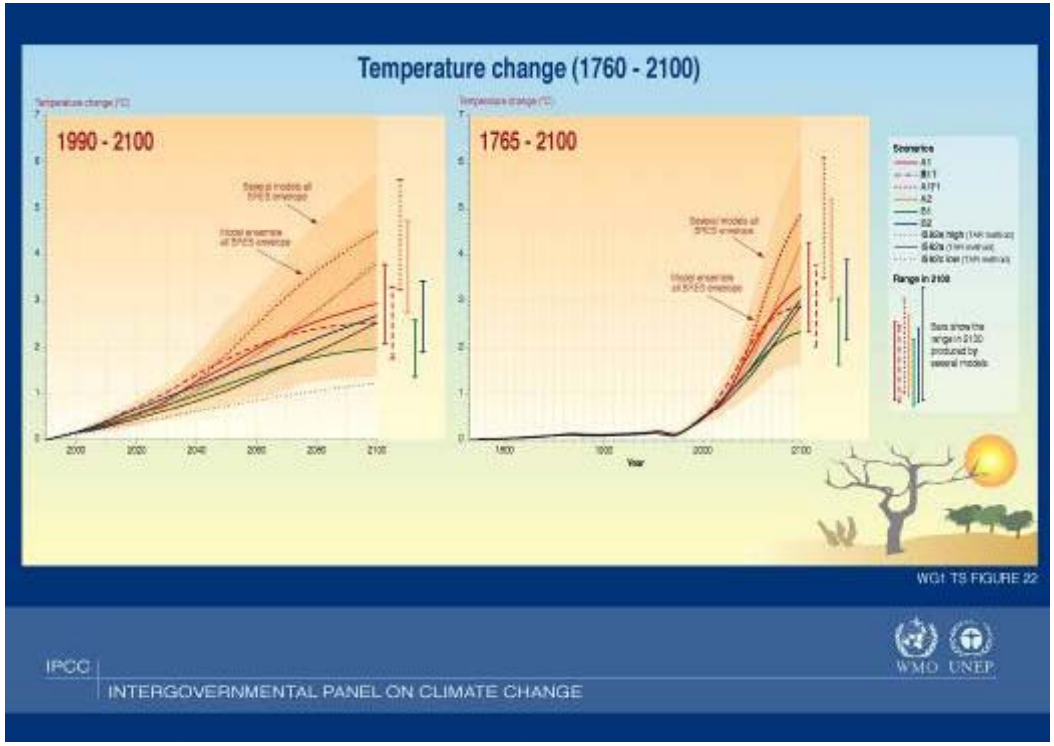
€	energy
€ €	productivity
€ € €	health

Need for flexibility + robustness

Organizations change continuously



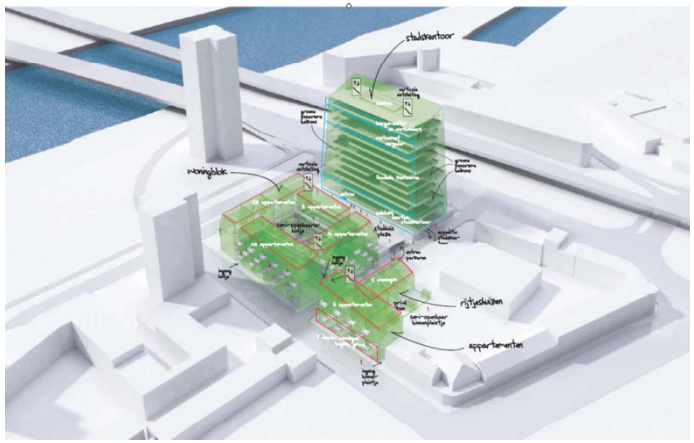
source: www.futuresense.com



Increasing real world complexity

Deutsche Bank
Greentowers
2009

Venlo



Virginia Tech
Lumenhaus
Solar Decathlon 2009

source: High Performing Buildings, spring 2008

Current practice

Is to design and operate buildings
to minimize dissatisfaction

source: High Performing Buildings, spring 2008

Goal and vision for 2050 *Eindhoven Energy Institute*

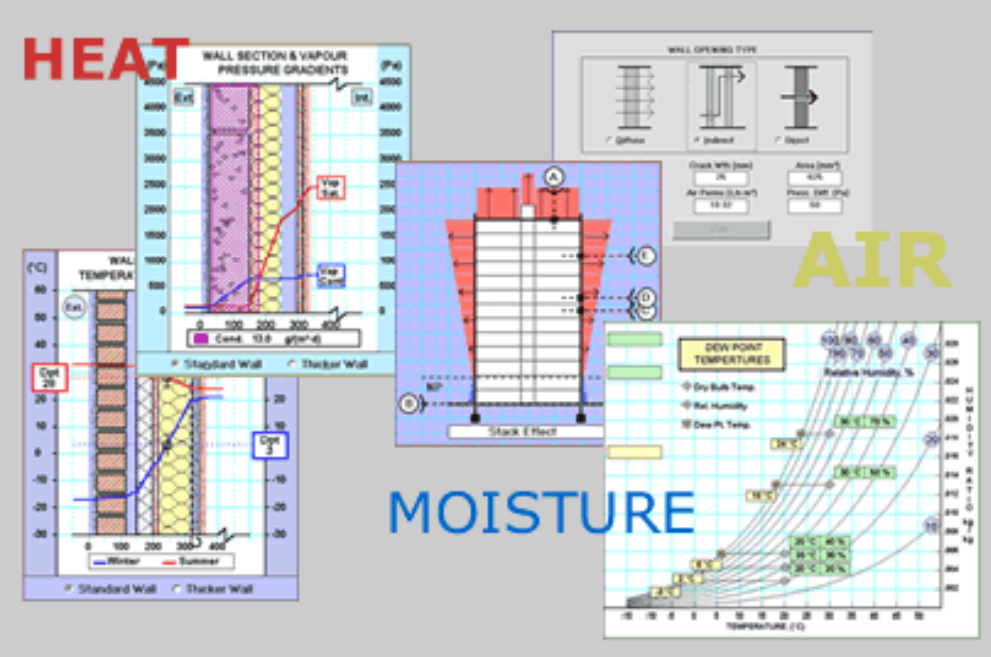
- **A sustainable energy-positive built environment with indoor environmental quality optimized for health, comfort and/or productivity, while considering ecological/ climatic requirements and economics**

- **Requires a multiscale/ multiphysics and transdisciplinary approach which:**
  - **addresses technological solutions for energy generation, storage, distribution and conservation, and**
  - **integrates and optimizes these in design, construction and operation of new and existing buildings**

So - both new and refurbishment – future projects face huge challenges that seem too complex for traditional tools and approaches

Traditional tools

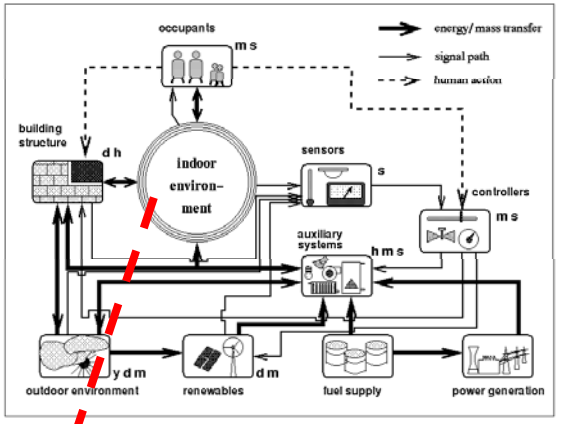
- mono-disciplinary
- solution oriented
- narrow scope
- static
- extreme conditions
- analytical methods (exact solution of very simplified model of reality)

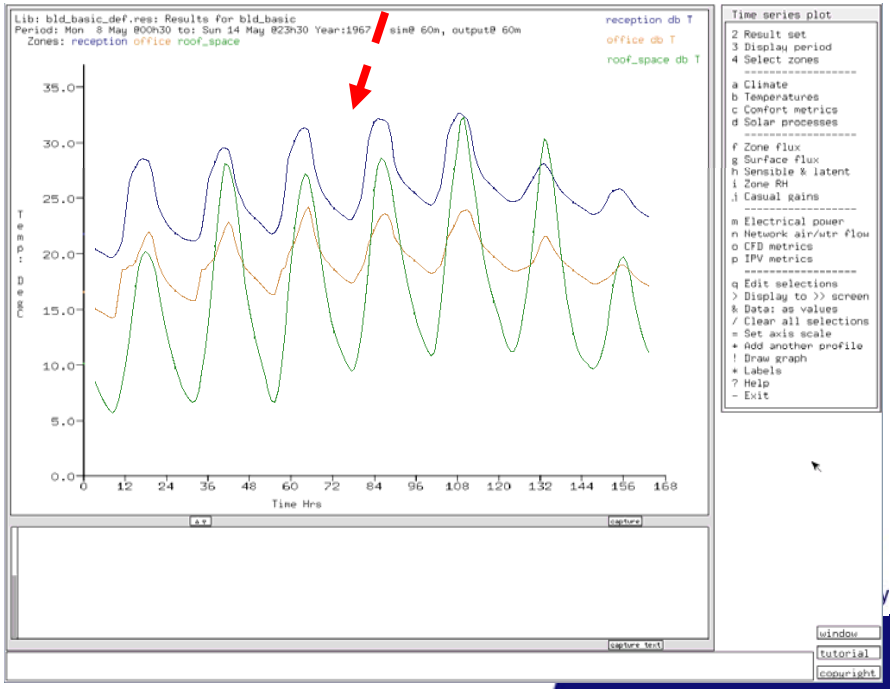


source: www.virtual-north.com

Simulation tools

- multi-disciplinary
- problem oriented
- wide(r) scope
- dynamic
- all conditions
- numerical methods (approximate solution of realistic model of reality)

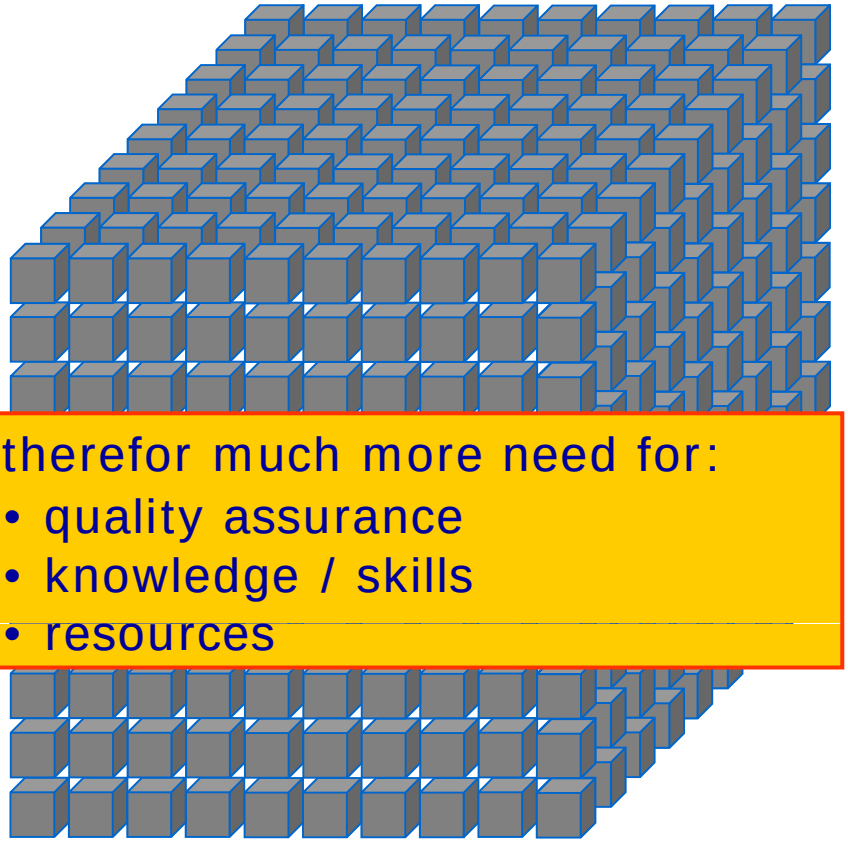




Traditional vs. simulation tools

fundamental difference between traditional and simulation tools is in the **complexity**

traditional models
– perhaps 10 variables



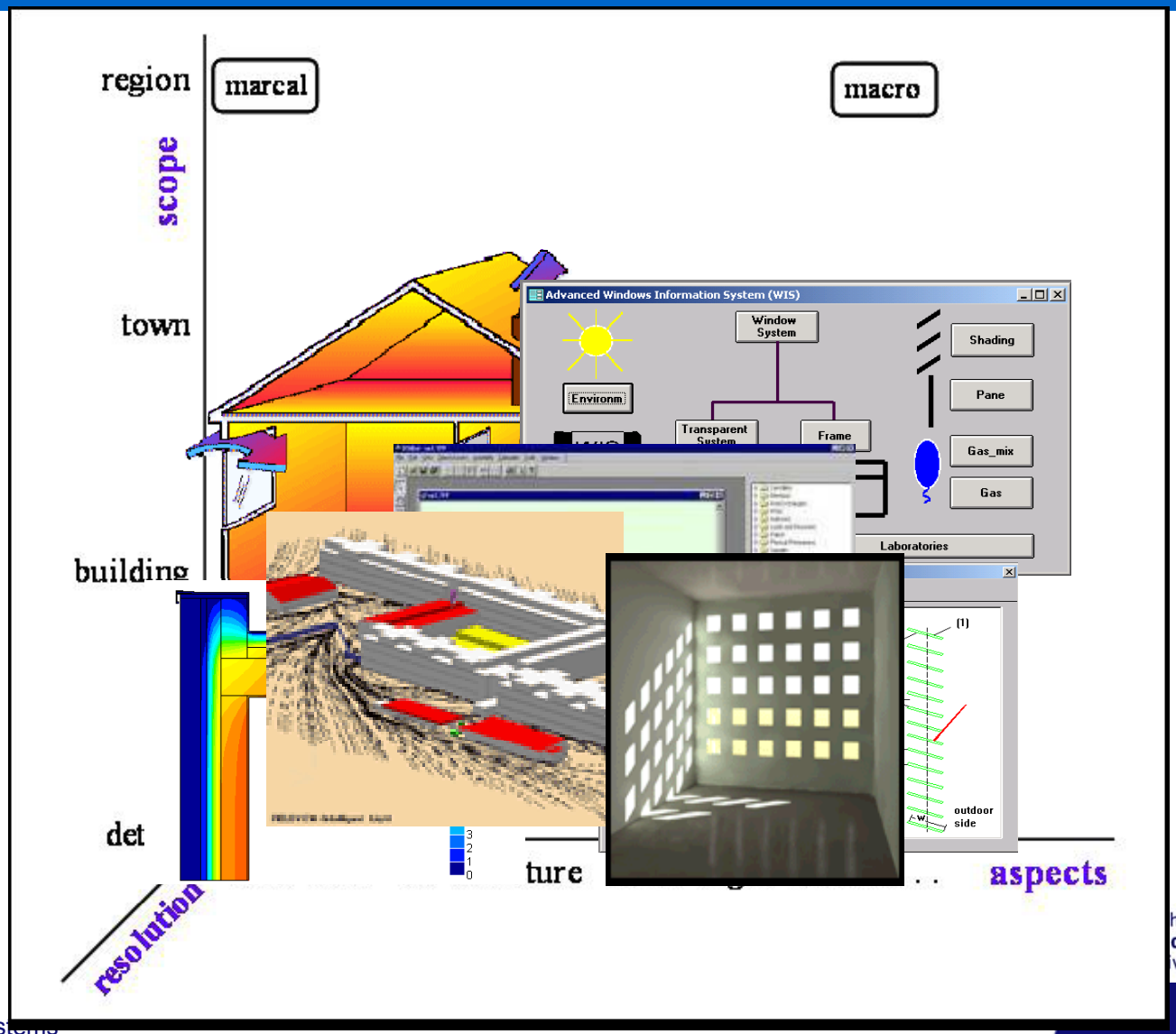
therefor much more need for:
- quality assurance
- knowledge / skills
- resources

computer simulation
– often > 10,000 variables

source: IBPSA-USA

Universiteit Eindhoven University of Technology

Building simulation tools



Building simulation use – example

A.C. van der Linden et al. / Energy and Buildings xxx (2005) xxx–xxx

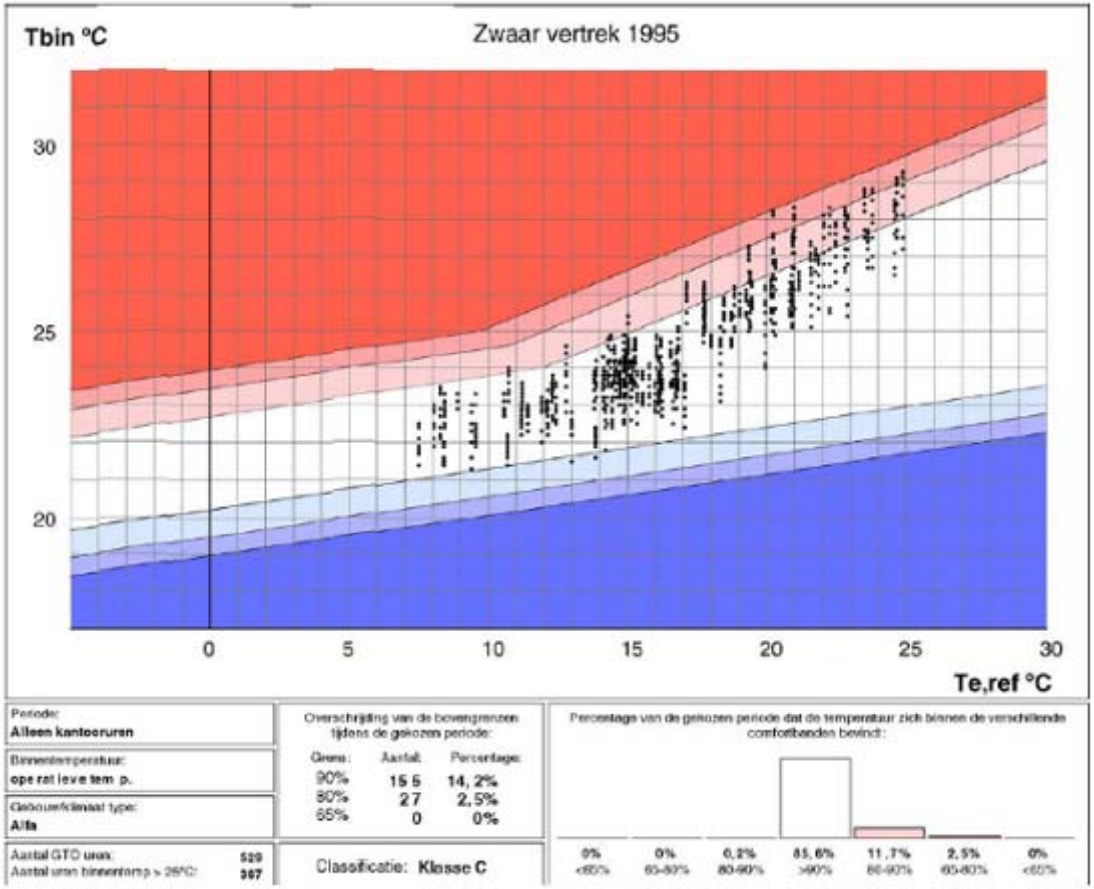
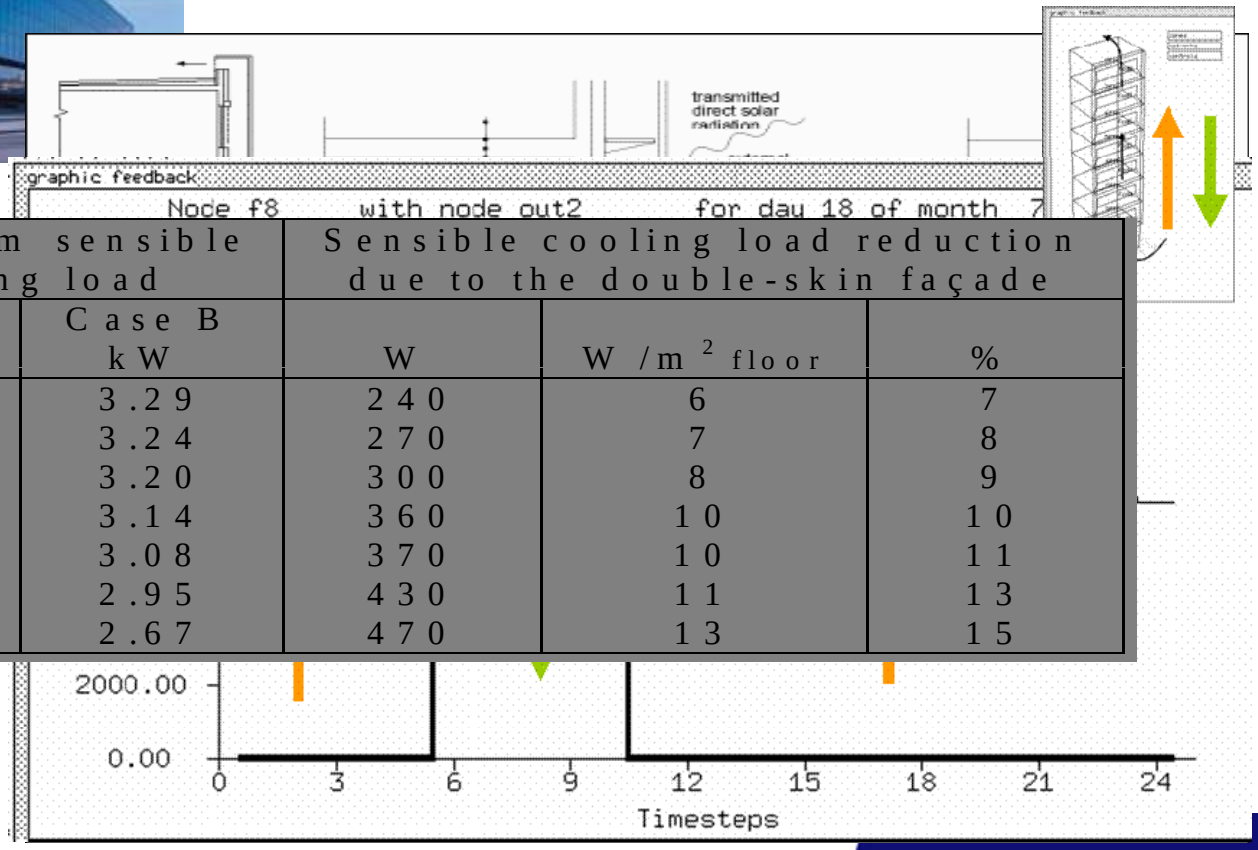


Fig. 6. The situation (medium–heavy building) of Fig. 4 now calculated for the months May–September 1995.

Building simulation use – example



Floor level	Maximum sensible cooling load		Sensible cooling load reduction due to the double-skin façade		
	Case A kW	Case B kW	W	W /m^2 floor	%
8 th	3.53	3.29	240	6	7
7 th	3.51	3.24	270	7	8
6 th	3.50	3.20	300	8	9
5 th	3.50	3.14	360	10	10
4 th	3.45	3.08	370	10	11
3 rd	3.38	2.95	430	11	13
2 nd	3.14	2.67	470	13	15

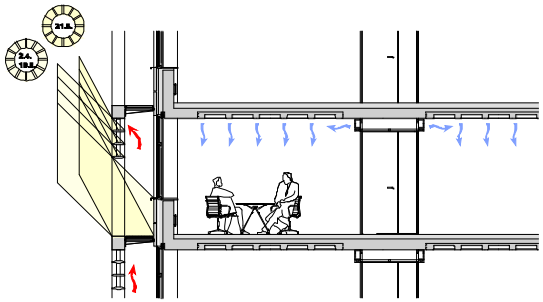
Building simulation use - example

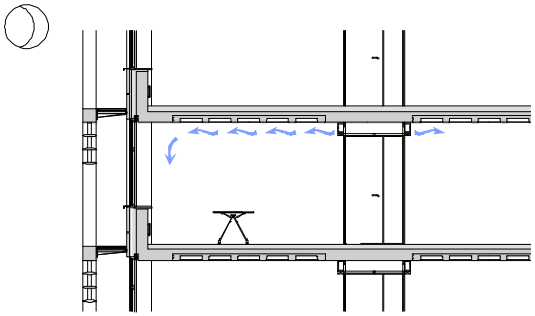
Passive cooling

- External shading
- High thermal mass
  (exposed floor / ceiling, ribs)

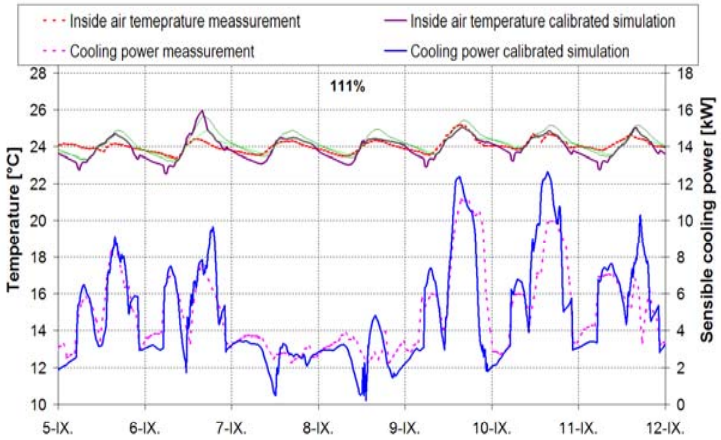
Low energy cooling

- All air system
- Night ventilation
- Top cooling
- Heat recovery

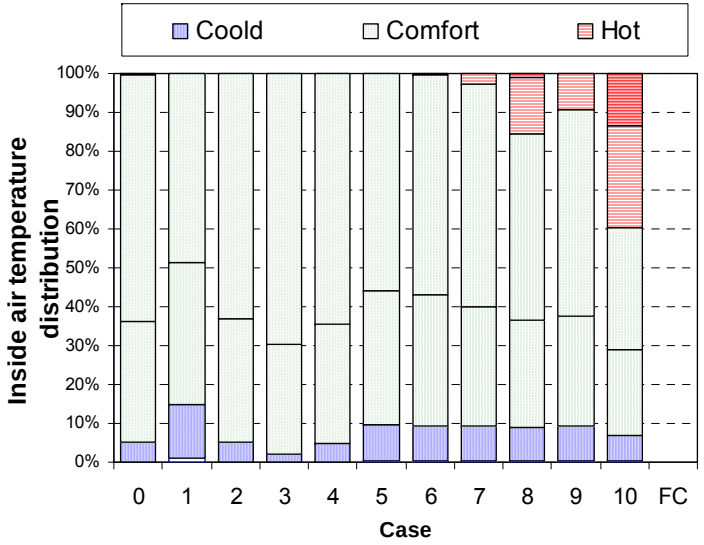


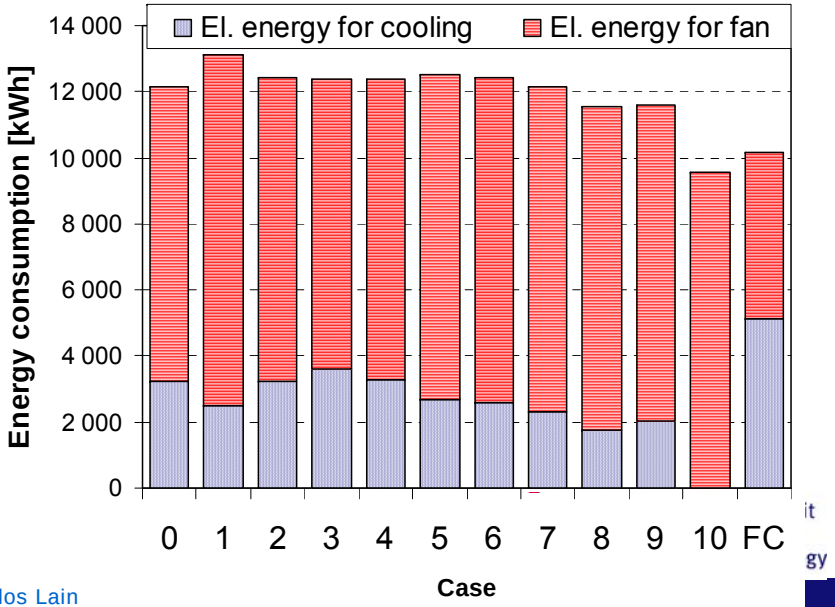


Building simulation use - example



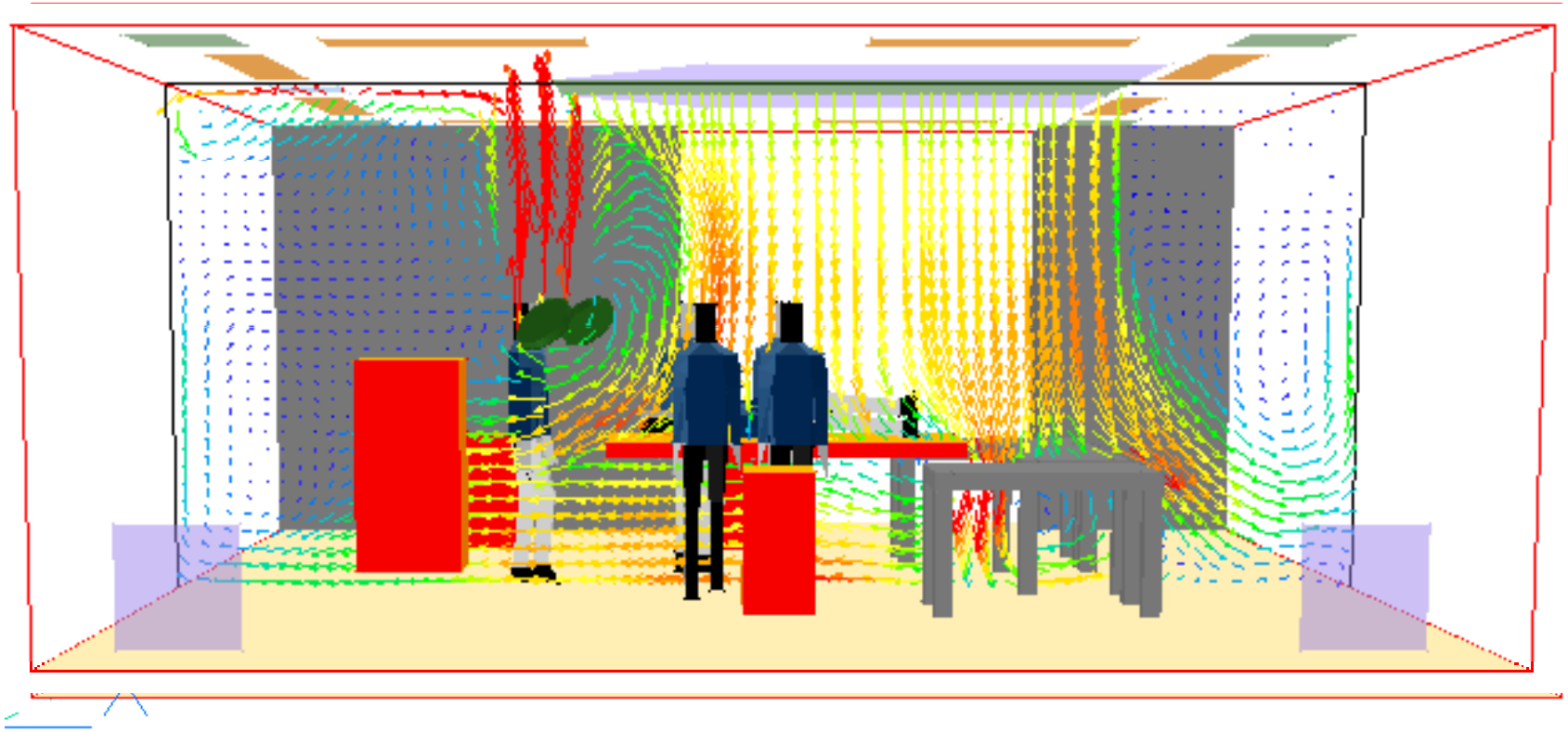
- **Using calibrated building + systems model, 10 operation scenarios were simulated: 6 scenarios with various combinations of flow rates and control periods, 5 scenarios with reduced cooling coil capacity**





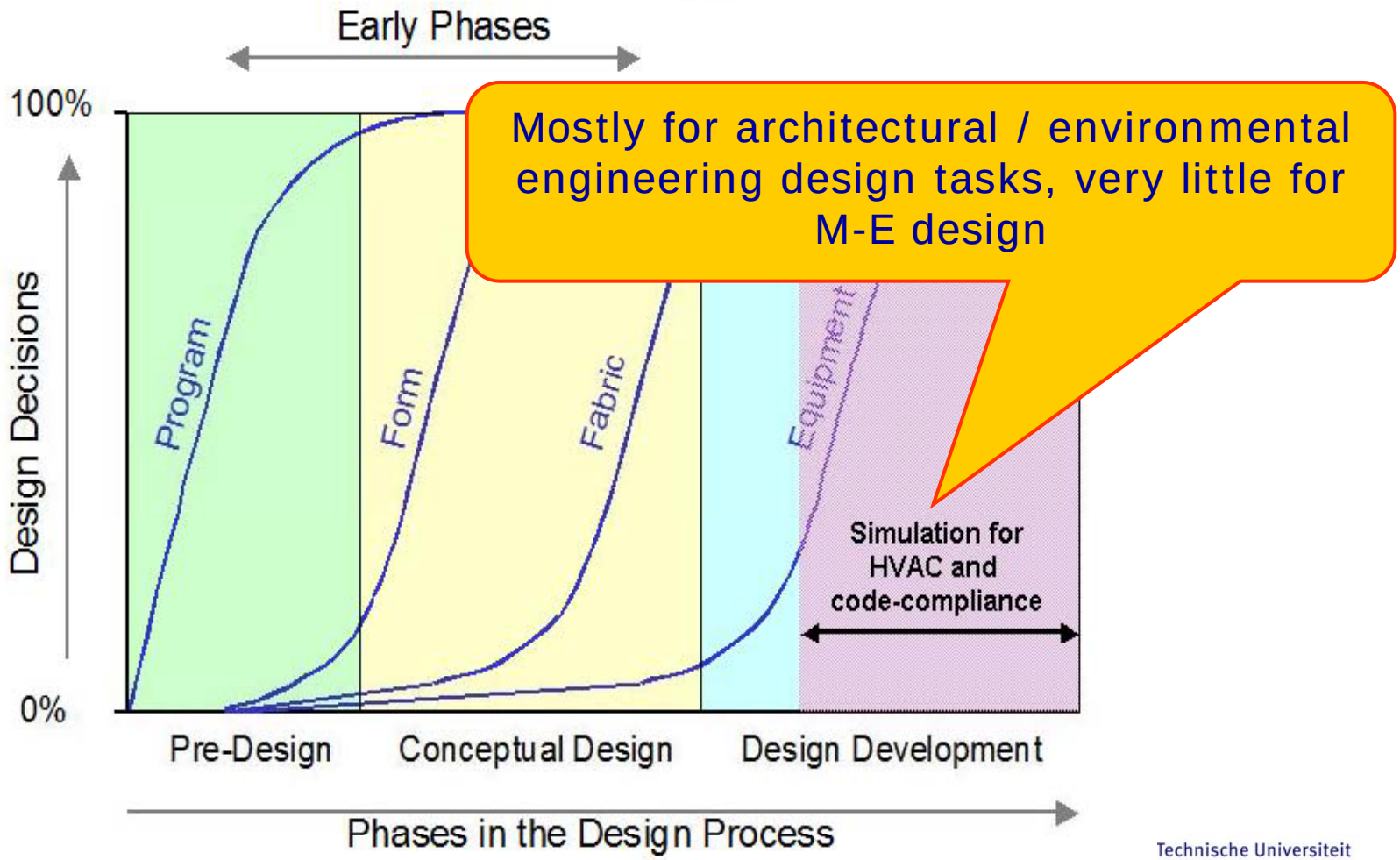
source: Milos Lain

Building simulation use - example



Source: Wiebe Zoon

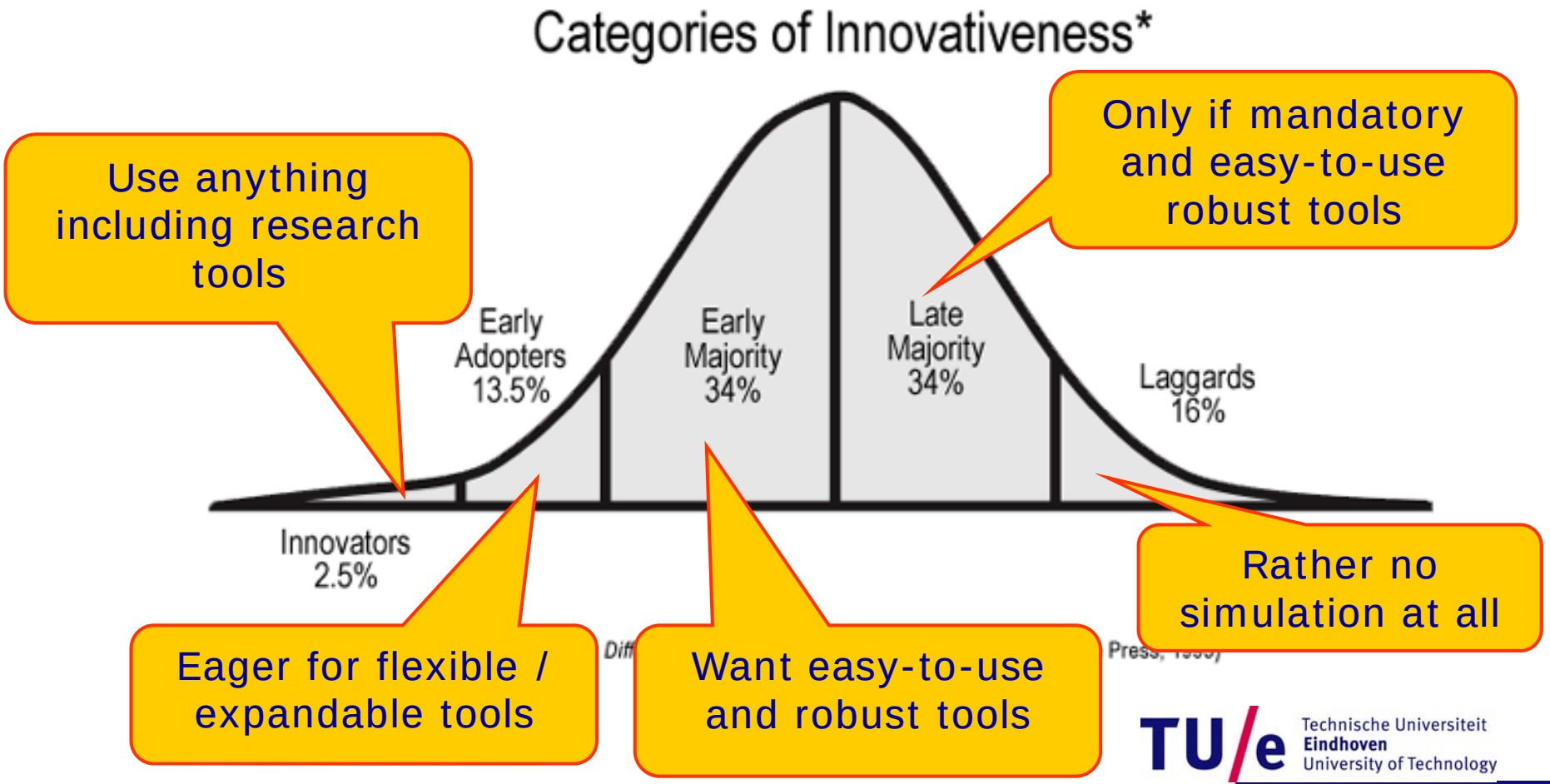
Building simulation use - current



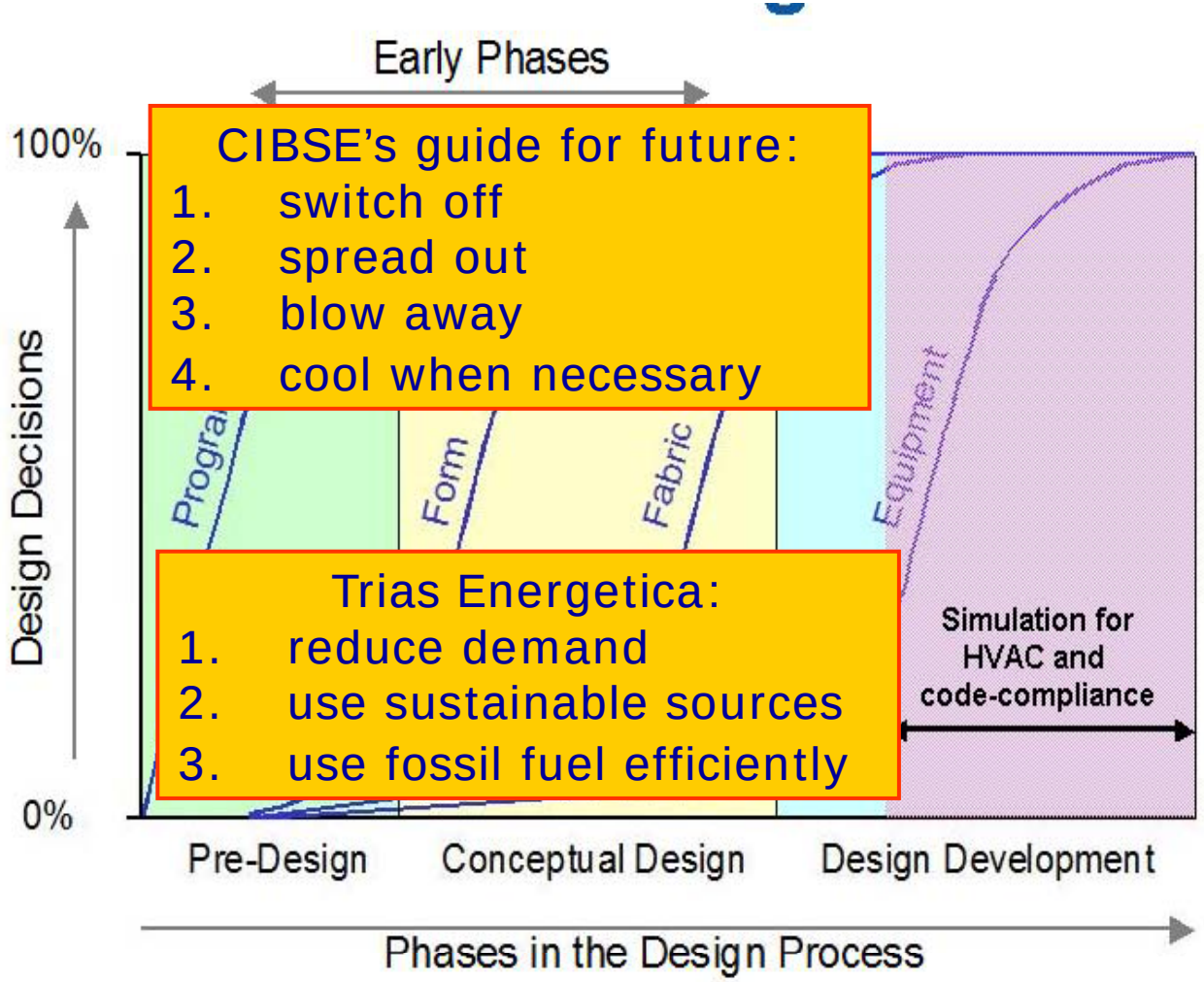
Mostly for architectural / environmental engineering design tasks, very little for M-E design

source: P Torcellini / P Ellis

Building simulation user types

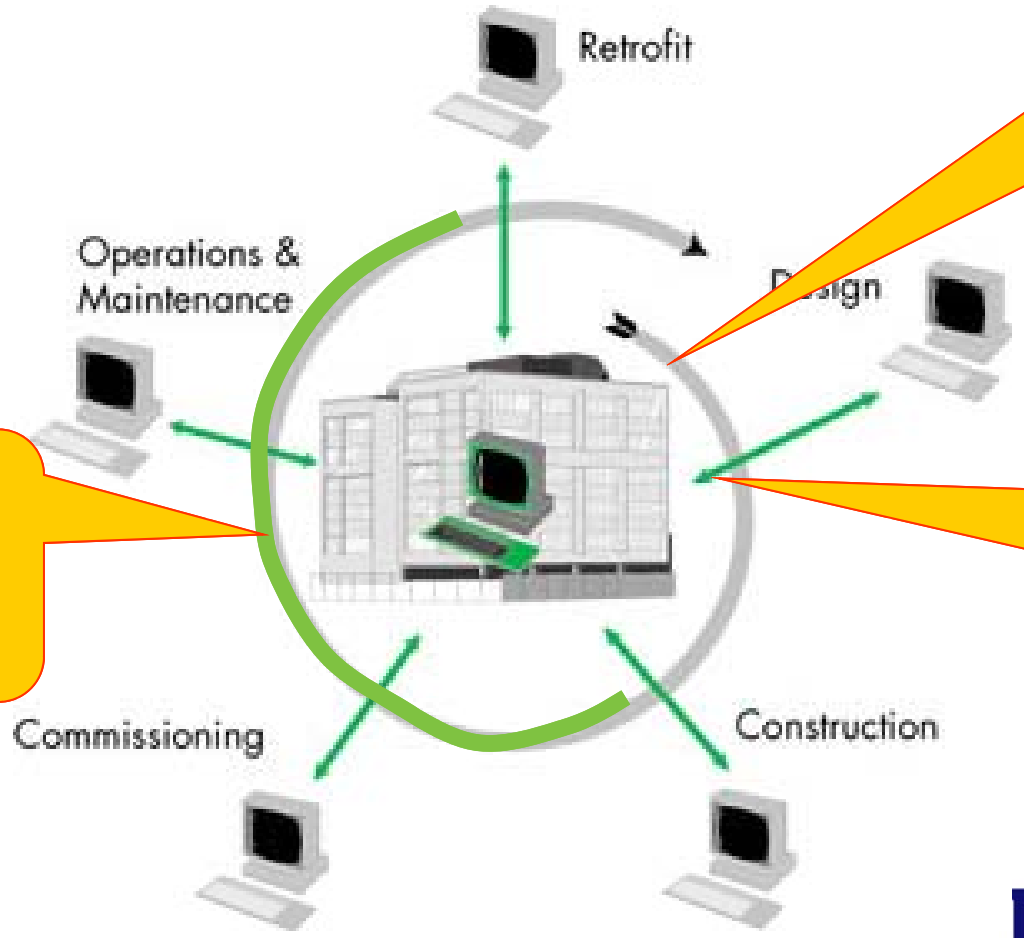


Simulation in design …



source: P Torcellini / P Ellis

Simulation in design, but



but early design decisions have much more impact

it is used mainly for design development

and is rarely used to optimize real performance

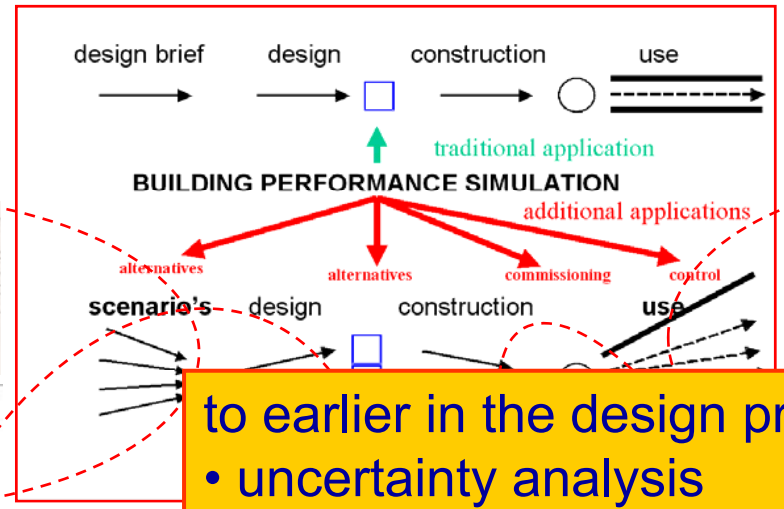
source: eetdnews.lbl.gov

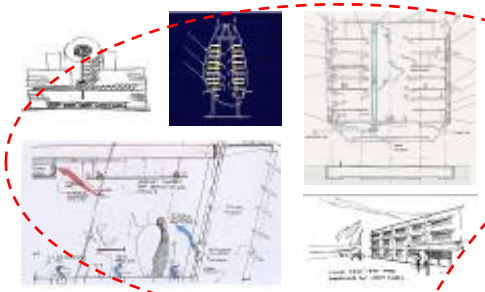
Main building simulation challenges

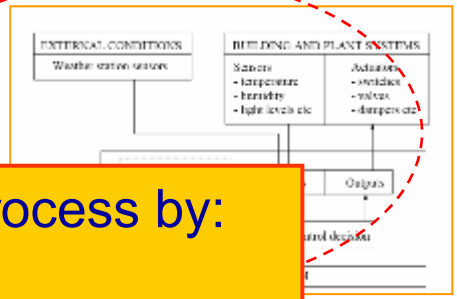
- **Quality assurance**
  - **Educate and certify users**
  - **Develop application procedures**
  - **Increase physical validity of tools**
- **Provide better design support**
  - **Early phase design support**
  - **Multi-scale (construction detail … district level)**
  - **Uncertainty and sensitivity analysis**
  - **Robustness analysis (use/ environmental scenarios, …)**
  - **Optimization under uncertainty**
  - **Inverse approach (what if => how to)**
  - **Multi-physics (power flow modeling, …)**
  - **Integrate in design process (BIM, process modeling, …)**
- **Building operation and management support**
  - **Accurate in-use energy consumption prediction**
  - **Model predictive (supervisory mimo) control**

Expanding simulation scope

UCL Belgium







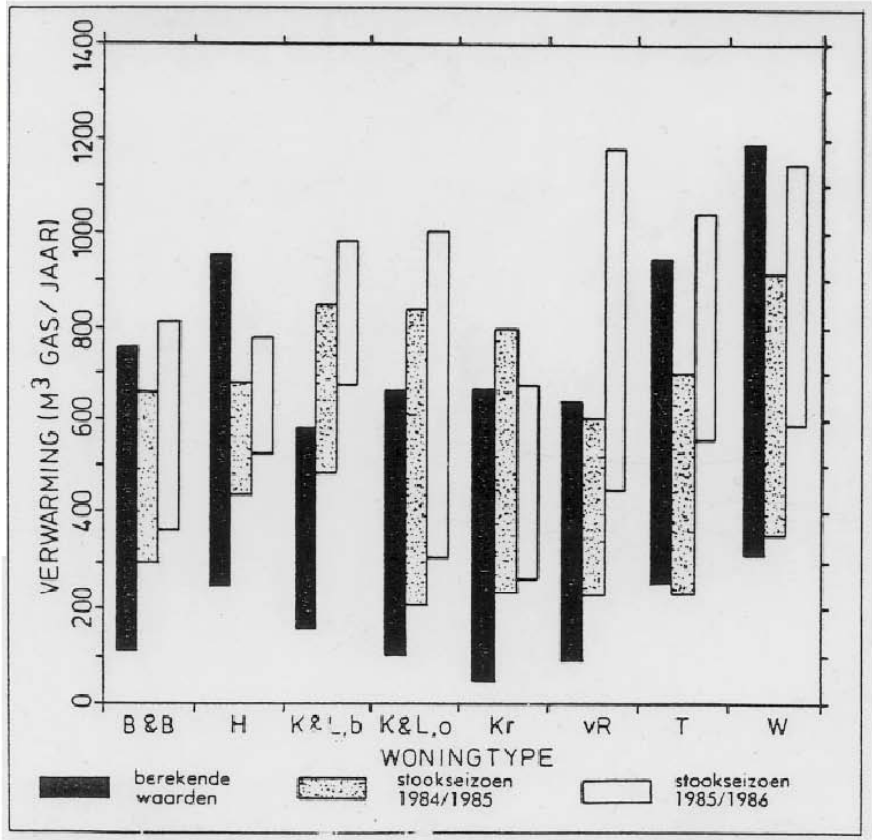
Gazi Univ. Turkey

to earlier in the design process by:
- uncertainty analysis
- sensitivity analysis

- multi-objective decision making
- optimization under uncertainty

Technische Universiteit Eindhoven University of Technology

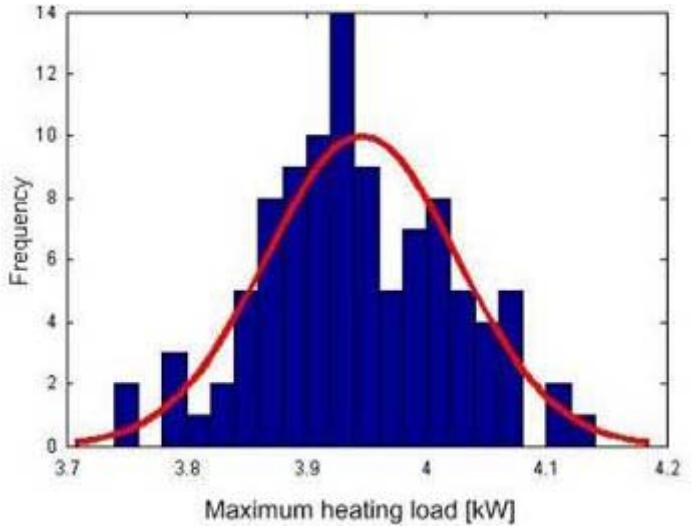
Uncertainty analysis *(1984 technology)*



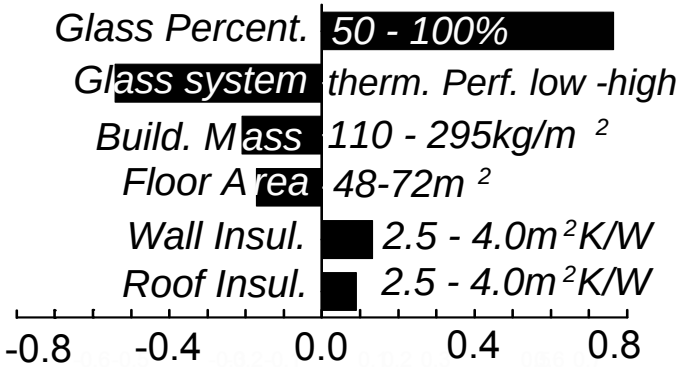
Variability due to (stochastic) occupant behaviour
in terms of Tset, Qint, ACR

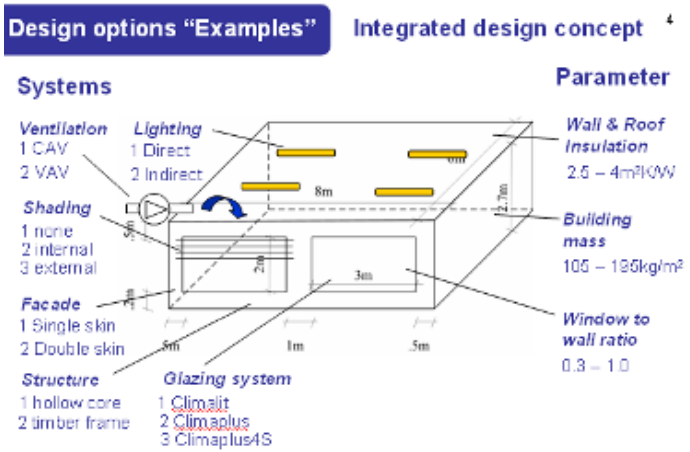
Uncertainty & sensitivity analysis

Variability due to physical parameter uncertainty



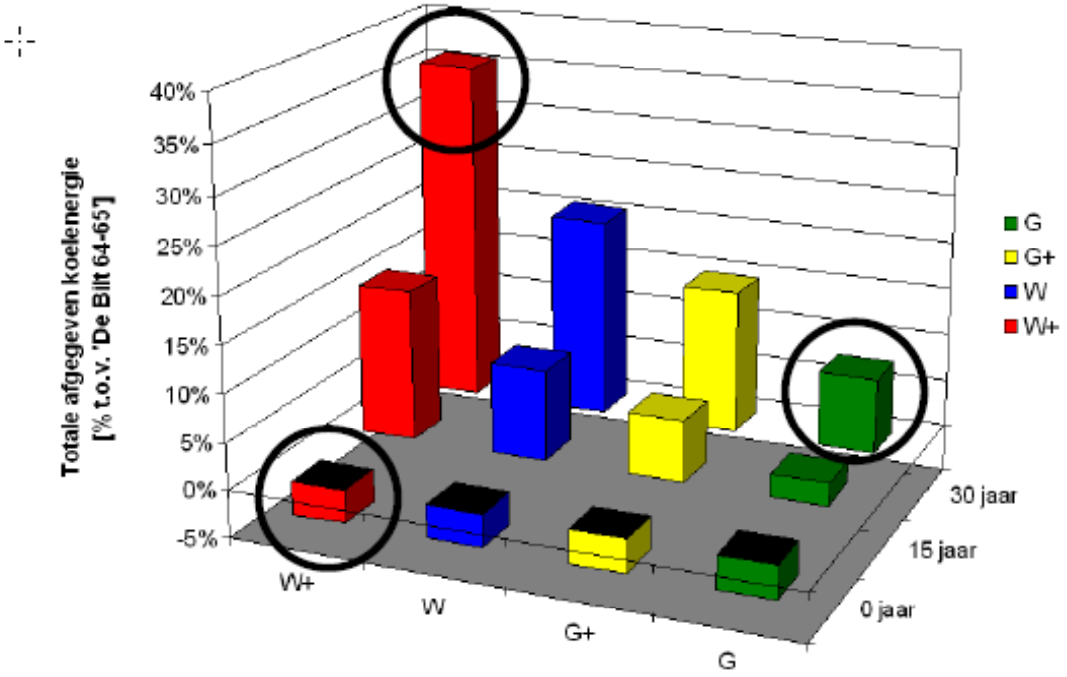
Sensitivity of design parameter on uncertainty of cooling demand

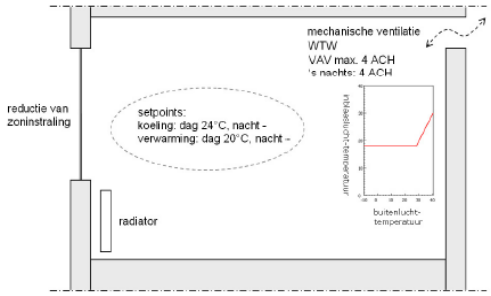




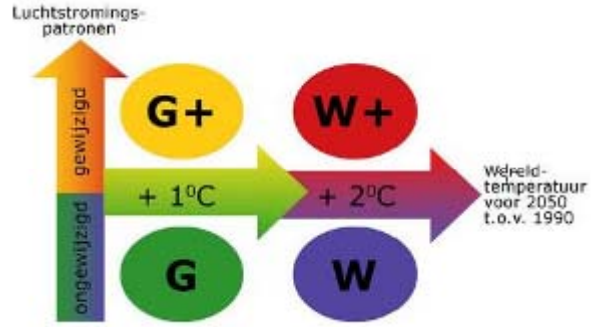
Source: Hopfe & Struck

Uncertainty & robustness analysis





afgegeven koelenergie in % t.o.v. 'De Bilt 64-65', topkoeling-concept,



Source: Janneke Evers

Uncertainty & robustness analysis

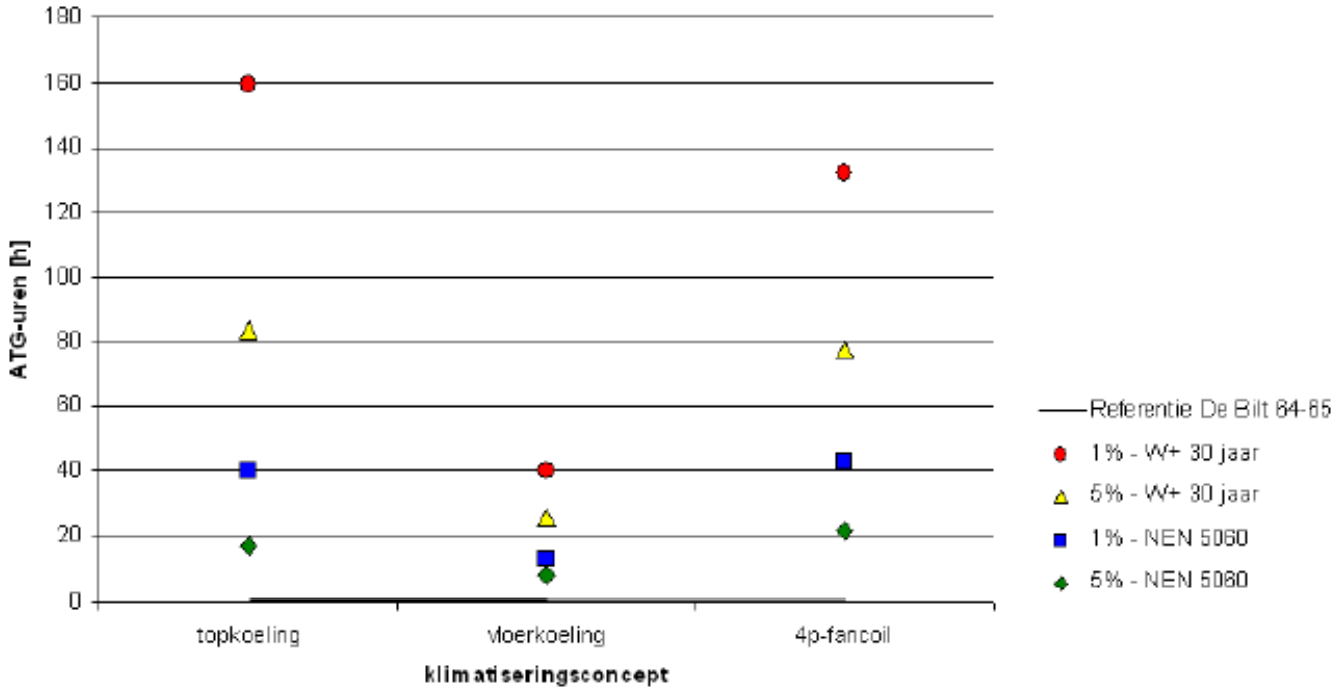
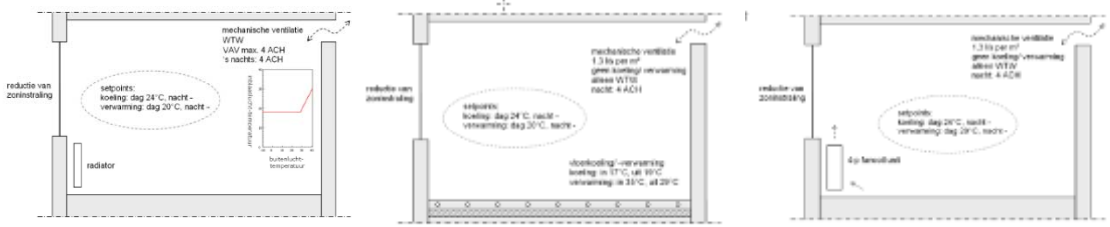


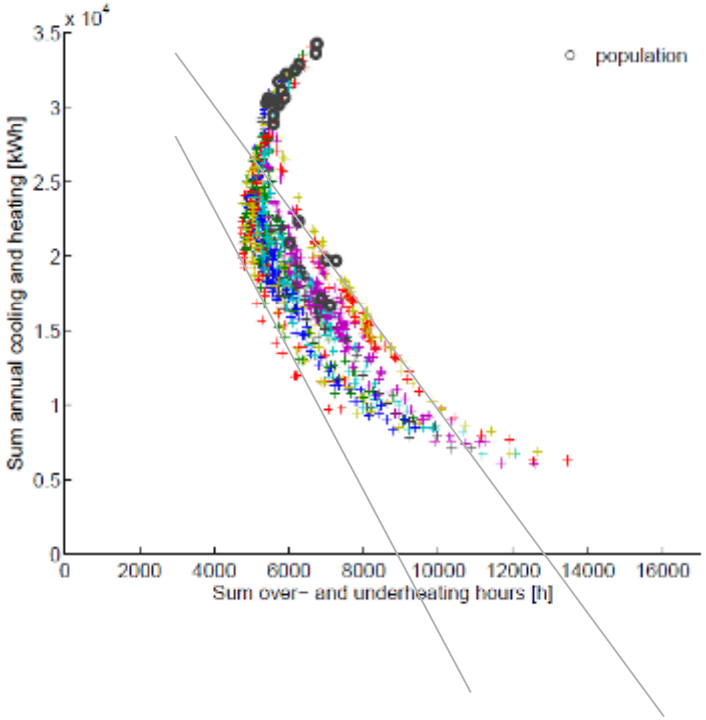
Fig. 6.4: Vergelijking van 3 klimatiseringsconcepten, ATG-uren, 'klimaatbestanden voor de toekomst', installatie gedimensioneerd op ATG-klasse B met 'De Bilt 64-65'



Source: Janneke Evers

Uncertainty & optimization

Before optimization
(initial population)

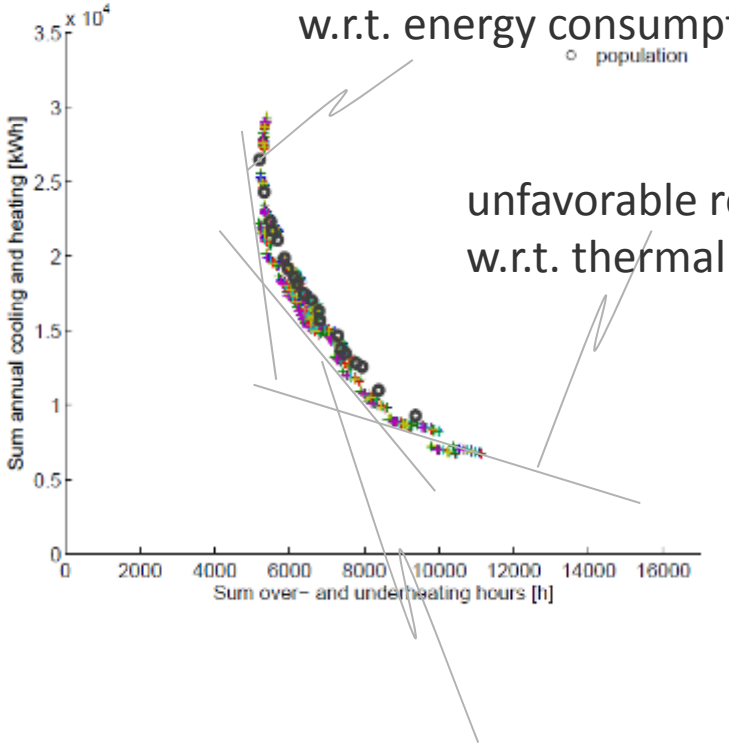


Wide uncertainty
margin for unoptimized
solutions

After optimization

unfavorable region
w.r.t. energy consumption

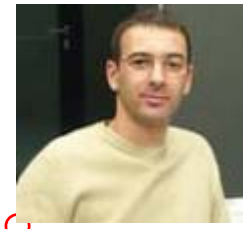
unfavorable region
w.r.t. thermal comfort



Linear trade-off

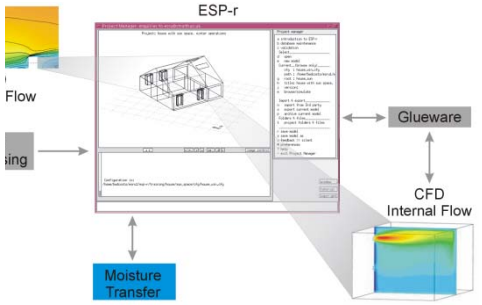
Source: Christina Hopfe

Co-simulation *(by run-time coupling)*

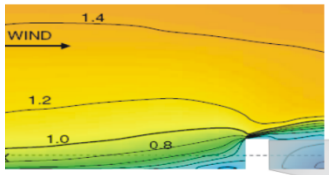


research issues:
- which data
- how exchange
- what frequency

- speed
- stability
- accuracy



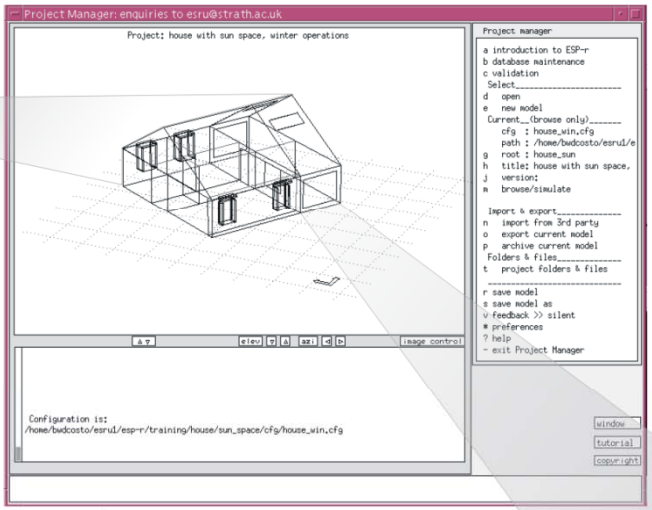
Whole building heat, air & moisture



CFD
External Flow

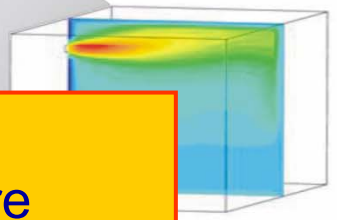
Pre
Processing

ESP-r



Glueware

CFD
Internal Flow



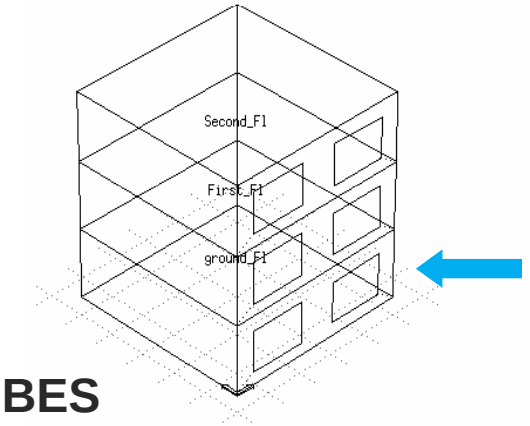
Moisture
Transfer

deliverables:
- prototype software
- coupling procedure
- coupling validation

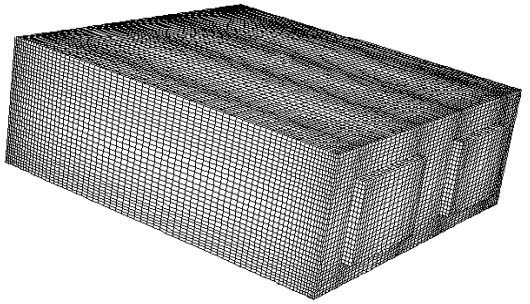
HAMPE – case study

Model

- Volume: 10 (m) *10 (m) * 3.33 (m)
- 12 surfaces
- Duration = 1 day (31st of March)
- 2 time steps per hour
- Location: Brussels
- Free floating temperature



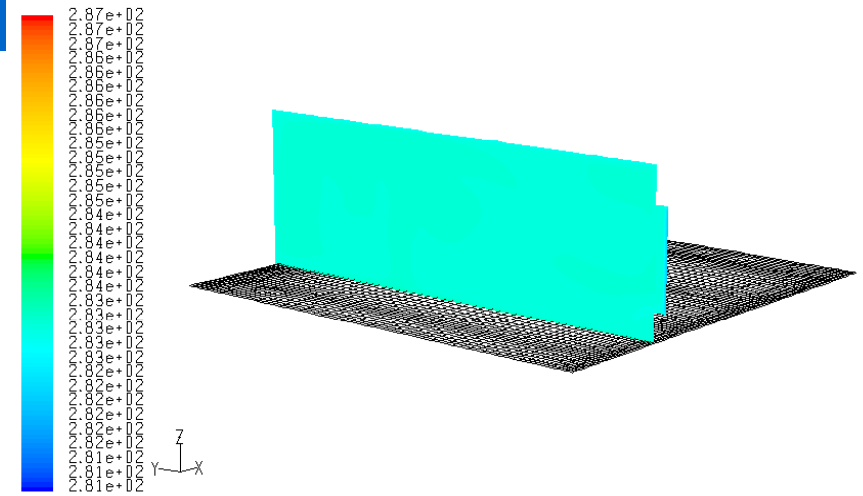
BES



CFD

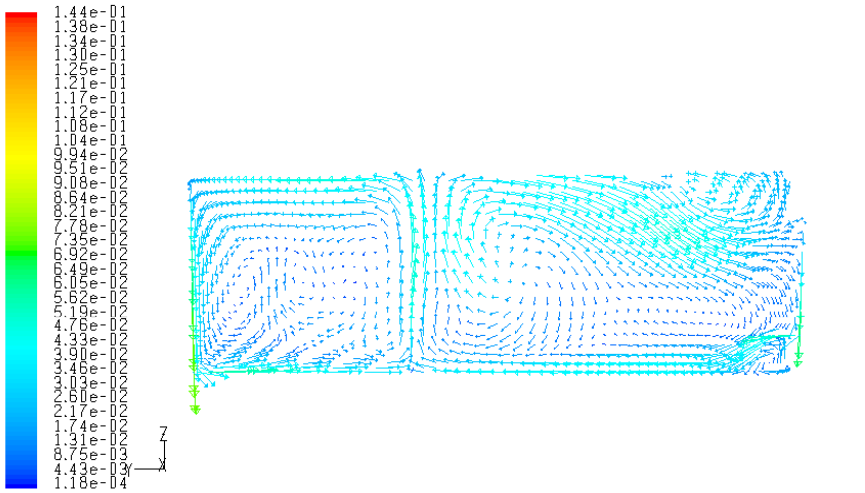
Technische Universiteit Eindhoven University of Technology

HAMPE – case study



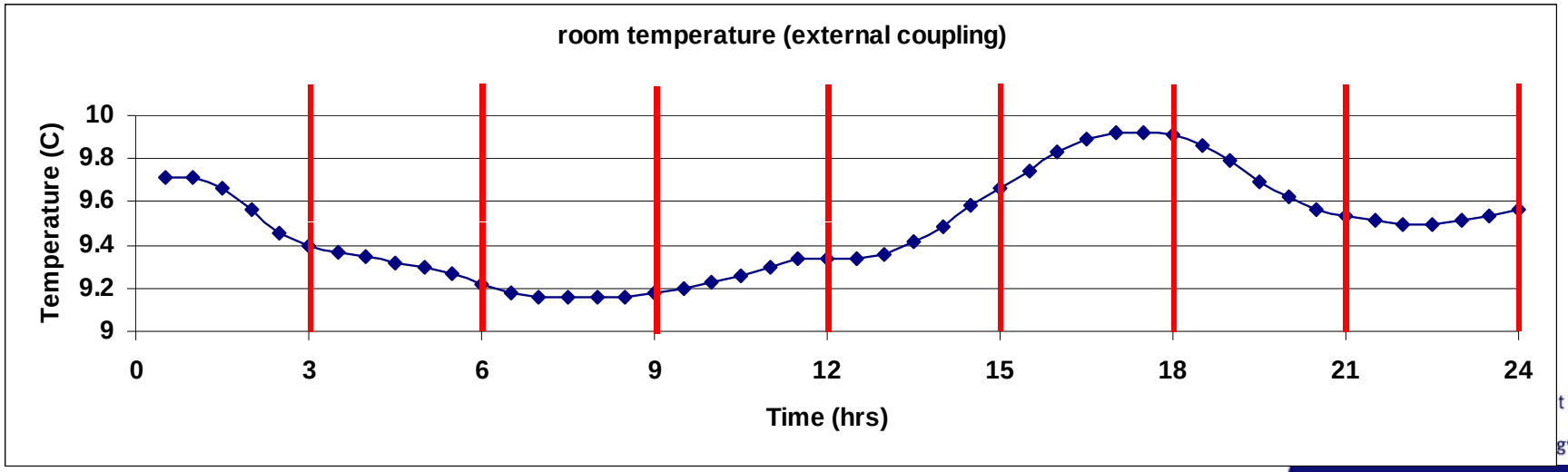
Contours of Static Temperature (k)

Sep 05, 2007
FLUENT 6.1 (3d, segregated, atm)



Velocity Vectors Colored By Velocity Magnitude (m/s)

Sep 05, 2007
FLUENT 6.1 (3d, segregated, atm)



Source: Daniel Costola + Mohammad Mirsadeghi

Application oriented

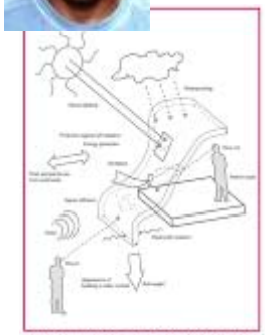
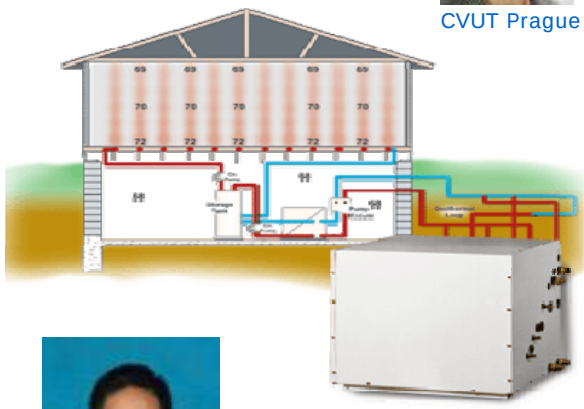


Fig 1: Functions - façade [Knaack, 2007]

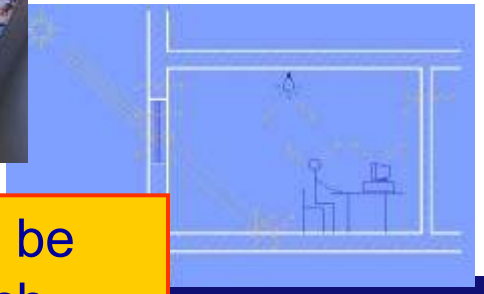
Fig 2: Inspiration – Chameleon

Fig 3: Inspiration - Human body

CVUT Prague



CVUT Prague



Identifies shortcomings and barriers to be addressed in our more general research

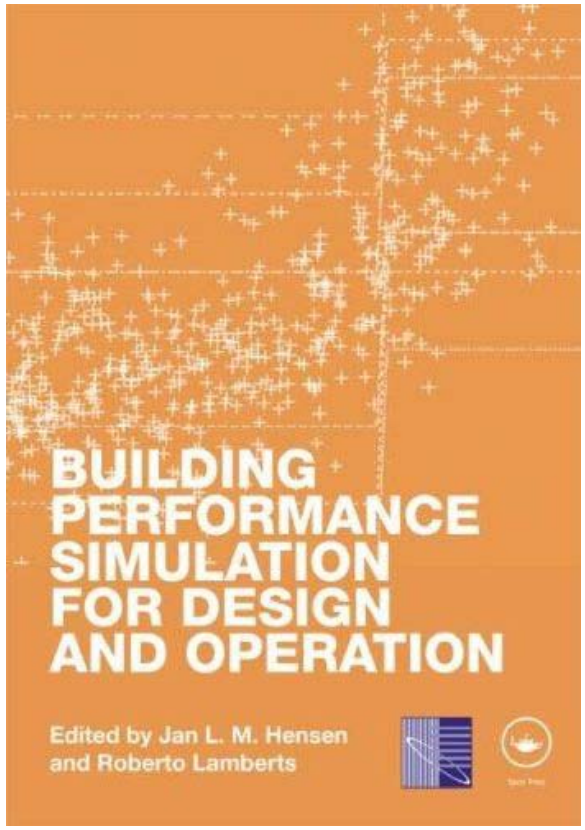
Conclusions

- **Building simulation has come a long way since “1970”**
- **Very promising technology for addressing major technical “ASHRAE / AIA” challenges during next decades**
- **Needs improvements in terms of:**
  - **Quality assurance (tools, users & use)**
  - **Usefulness and integration in/ for performance based design and operation of buildings**
- **Opportunities for cooperation ASHRAE / AIA / IBPSA**
  - **R&D, Best Practice Examples, Guidebooks, Courses, Tool Accreditation, User Certification, …….**

My main interests while at LBNL-EETD

- **Co-simulation using BCVT + FMI**
- **Modelica**
- **User Facility for Net-Zero and Low Energy Buildings**
- **LearnHVAC**
- **Cooperative research proposals**
  - **EU / NL / US**
  - **IEA Annex / IBPSA Task proposal**
  - **…**
- **…**

Thank you !



www.bwk.tue.nl/bps/hensen

Technische Universiteit
Eindhoven
University of Technology